56F8300 3-Phase Permanent Magnet Synchronous

Motor Vector Control using Processor Expert

Targeting Document

MC56F8300
16-bit Digital Signal Controllers

8300PMSMTD
Rev. 0
1/2005

freescale.com

freescale™
semiconductor

Document Revision History

Version History	Description of Change
Rev 0	Initial public release

3-Phase Permanent Magnet Synchronous Motor Vector Control on Processor Expert

This application exercises vector control of the 3-Phase Permanent Magnet Synchronous Motor (PMSM) using Processor Expert (PE), a 56F8346, 56F8357, or 56F8367 EVM board and a 3-Phase AC / BLDC High-Voltage Power Stage.

Applications developed for this demonstration board were not designed for the 56F8100 devices. The 56F8300 demonstration board does, however, fully support 56F8100 software development.

Note: The PC master software referenced in this document is also known as Free Master software.

1. Specifications

This application performs principal vector control of the 3-phase PMSM using a 56F8300 processor. The concept of the application is a speed closed-loop PM synchronous drive using a vector control technique. The control technique obtains d and q current components from regularly sampled 3-phase stator currents. The d and q current components are then controlled separately. The q component corresponds to torque and the d component corresponds to flux. An incremental encoder is used to derive the actual rotor speed.

The Actual Speed, derived from a quadrature decoder, monitors the actual behavior of the system, and is compared with the reference signal (Required Speed).

Protection is provided against drive faults Overcurrent, Overvoltage, Undervoltage, and Overheating.

System Outline

The system is designed to drive a 3-phase permanent magnet synchronous motor. The application has the following specifications:

- Vector control technique used for PMSM control
- Speed control loop
- Targeted for a 56F8346EVM, 56F8357EVM, or 56F8367EVM
- Runs on a 3-phase PMSM control development platform at a variable line voltage, 115V AC and 230V AC (range of -15% to +10%)
- Motor mode
- Generator mode
- DCBus brake
- Minimum speed 50rpm
- Maximum speed 3000rpm at input power line 230V AC
- Maximum speed 1500rpm at input power line 115V AC
- Fault protection

- Interfaces:
  - Manual interface
    - RUN / STOP switch
    - UP / DOWN push buttons control
    - LED indication
  - PC master software remote control interface
    - START MOTOR / STOP MOTOR push buttons
    - Speed set-up
- PC master software remote monitor
  - Software monitor interface provides information about:
    - Required Speed
    - Actual motor speed
    - PC master software mode
    - START MOTOR / STOP MOTOR controls
    - Drive fault status
    - DCBus voltage level
    - Drive status
    - Mains detection
  - Software speed scope
    - Observes actual and desired speed
  - Software recorder for:
    - Phase currents
    - d, q currents

Application Description

The vector control algorithm is calculated on Freescale's 56F8346EVM, 56F8357EVM, or 56F8367EVM. The algorithm generates 3-phase PWM signals for a PMSM inverter according to the user-required inputs, and measured and calculated signals.

The PMSM drive hardware components include:

- BLDC motor-brake set
- 3-phase AC / BLDC High-Voltage Power Stage
- 56F8346, 56F8357, or 56F8367 EVM board
- Legacy Motor Daughter Card (LMDC)
- In-line optoisolation box (Freescale Part # ECOPTINL), which is connected between the host computer and the EVM board

The BLDC motor-brake set incorporates a 3-phase BLDC motor and an attached BLDC motor brake. The BLDC motor has six poles. The incremental position sensor (encoder) is coupled on the motor shaft and position Hall Sensors are mounted between the motor and the brake. They allow position sensing if required by the control algorithm. Detailed motor-brake specifications are listed in **Table 1-1**.

Note: The application software is targeted for PMSM with sine-wave Back-EMF shape. In this demo application, the BLDC motor is used instead, due to the availability of the BLDC motor-brake SM40V + SG40N, supplied as Freescale Part #ECMTRHIVBLDC. Although the Back-EMF shape of this motor is not ideally sine-wave, it can be controlled by the application software. The drive parameters will be improved when a PMSM motor with an exact sine-wave Back-EMF shape is used.

Table 1-1 Motor Brake Specifications

Motor	Motor Type	6 poles, 3-phase, star connected, BLDC motor
	Speed Range	2500rpm (at 310V)
	Maximum Electrical Power	150W
	Phase Voltage	3 x 200V
	Phase Current	0.55A
Drive Characteristics	Speed Range	< 2500rpm
	Input Voltage	310V DC
	Maximum DCBus Voltage	380V DC
	Control Algorithm	Speed Closed-Loop Control
	Optoisolation	Required
Motor Characteristics	Motor type	6 poles, 3-phase, star connected, BLDC motor
	Speed Range	150W
	Maximum Electrical Power	150W

The drive can be controlled in two operating modes:

- In the **Manual operating mode**, the required speed is set by the UP / DOWN push buttons and the drive is started and stopped by the RUN / STOP switch on the EVM board
- In the **PC master software operating mode**, the required speed is set by the PC master software active bar graph and the drive is started and stopped by the START MOTOR and STOP MOTOR controls

Measured quantities:

- DCBus voltage
- Phase currents (Phase A, Phase B, Phase C)
- Power module temperature
- Rotor speed

The faults used for drive protection:

- Overvoltage (PC master software error message = *Overvoltage fault*)
- Undervoltage (PC master software error message = *Undervoltage fault*)
- Overcurrent (PC master software error message = *Overcurrent fault*)
- Overheating (PC master software error message = *Overheating fault*)

The following software tools are needed for to compile, debug, and load to the EVM, and to use remote control and monitoring, and the RUN / STOP switch and UP / DOWN buttons:

- Metrowerks CodeWarrior v. 6.1.2
- PC master software
- Processor Expert v. 2.94

Control Process

After reset, the drive enters the INIT state in manual operation mode.When the RUN / STOP switch is detected in the STOP position and there are no faults pending, the STOP application state is entered. Otherwise, the drive waits in the INIT state or if faults are detected, the drive goes to the FAULT state. In the INIT and STOP states, the operation mode can be changed from PC master software. In the manual operational mode, the application is operated by the RUN / STOP switch and UP / DOWN buttons; in the PC master remote mode, the application is operated remotely by PC master software.

When the Start command is accepted (using the RUN / STOP Switch or PC master software command), the rotor position is aligned to a predefined position to obtain a known rotor position. The rotor alignment is done at the first start command only. Required speed is then calculated according to UP / DOWN push buttons or PC master software commands (if in PC master software remote mode). The required speed goes through an acceleration/deceleration ramp. The comparison between the actual speed command and the measured speed generates a speed error. Based on the error, the speed controller generates a stator current, *Is_qReq*, which corresponds to torque. A second part of the stator current, *Is_dReq*, which corresponds to flux, is given by the Field Weakening Controller. Simultaneously, the stator currents *Is_a*, *Is_b* and *Is_c* are measured and transformed from instantaneous values to the stationary reference frame α, β, and consecutively to the rotary reference frame d, q (Clarke-Park transformation). Based on the errors between required and actual currents in the rotary reference frame, the current controllers generate output voltages *Us_q* and *Us_d* (in the rotary reference frame d, q). The voltages *Us_q* and *Us_d* are transformed back to the stationary reference frame α, β and, after DCBus ripple elimination, are recalculated to the 3-phase voltage system, which is applied on the motor.

Drive Protection

The DCBus voltage, DCBus current and power stage temperature are measured during the control process. They protect the drive from overvoltage, undervoltage, overcurrent and overheating. Undervoltage and overheating protection is performed by software, while the overcurrent and overvoltage fault signals utilize a fault input of the hybrid controller. Line voltage is measured during application initialization and the application automatically adjusts itself to run at either 115V AC or 230V AC, depending on the measured value.

If any of the previously mentioned faults occur, the motor control PWM outputs are disabled to protect the drive, and the application enters the FAULT state. The FAULT state can be left only when the fault conditions disappear and the RUN / STOP switch is moved to the STOP position in the manual mode and by the PC master software in the PC master software remote mode.

The application can run on:

- External RAM or Flash
- 3-Phase AC/BLDC High-Voltage Power Stage powered by 115V AC or 230V AC
- Manual or PC master software operating mode

The voltage level is identified automatically and the appropriate constants are set.

The 3-phase PM Synchronous Motor Control Application can operate in two modes:

1. **Manual Operating Mode**
   The drive is controlled by the RUN / STOP switch (S3) on the Legacy Motor Daughter Card (LMDC). The motor speed is set by the UP (S1) and DOWN (S2) push buttons on the LMDC; see **Figure 1-1**. In this application, the PWMA module output LEDs are used as USER LEDS. If the application runs and motor spinning is disabled (i.e., the system is ready), the GREEN USER LED (LED2, shown in **Figure 1-2**) will blink. When motor spinning is enabled, the USER LED is *On*. Refer to **Table 1-2** for application states. The actual state of the PWM outputs is indicated by PWMB output LEDs. If overcurrent, overvoltage or overheating occur, the GREEN USER LED (LED2) starts to flash quickly and the PC master software signals the type of fault identified. This state can be exited only by an application reset. It is strongly recommended that you inspect the entire application to locate the source of the fault before starting it again.

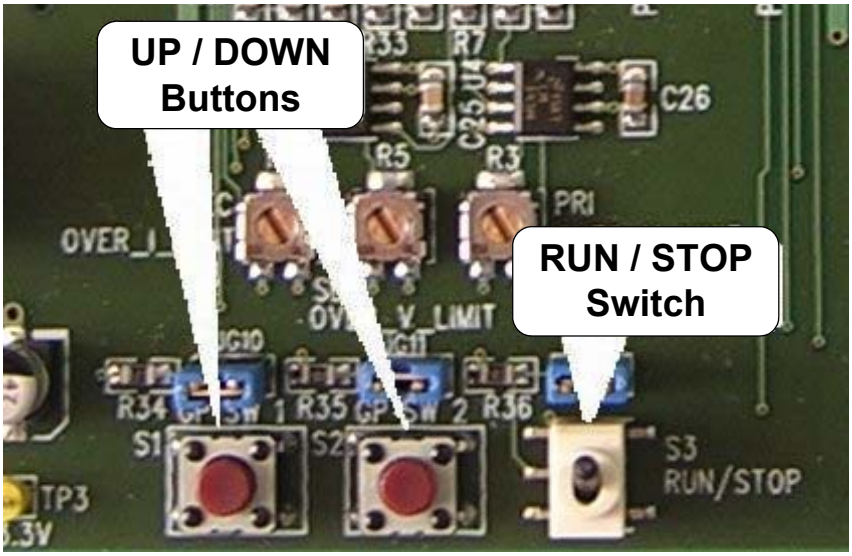

Figure 1-1 RUN / STOP Switch and UP / DOWN Buttons on the Legacy Motor Daughter Card (LMDC)

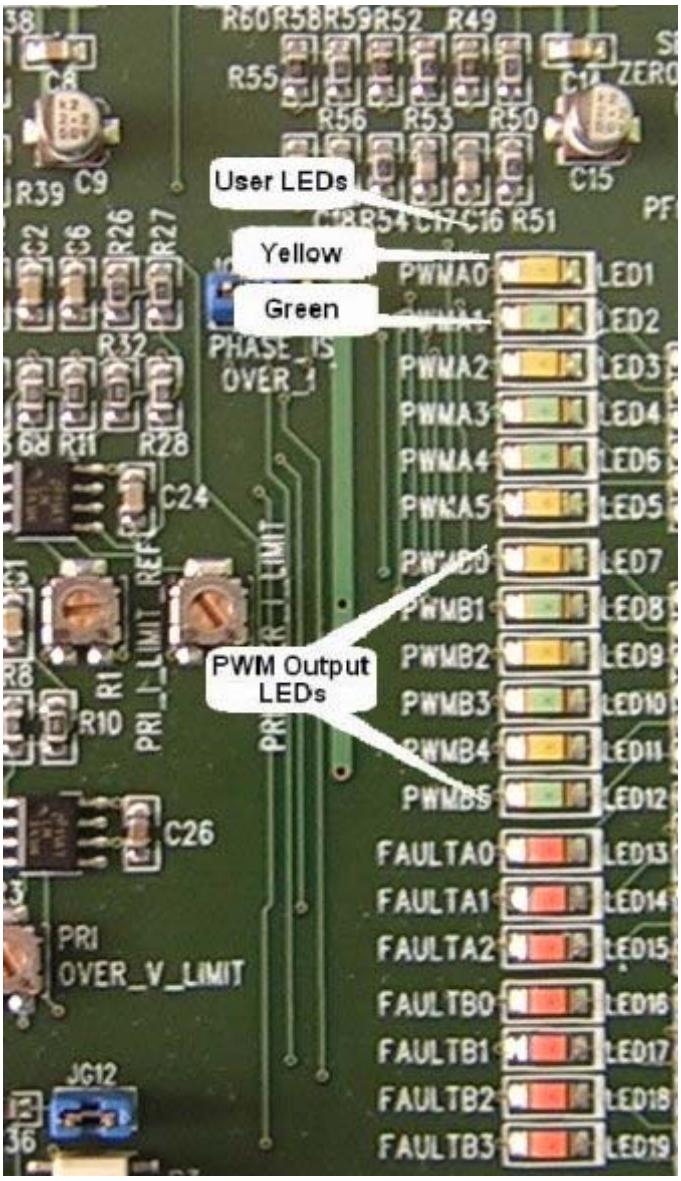

Figure 1-2 USER and PWM LEDS on the Legacy Motor Daughter Card (LMDC)

Table 1-2 Motor Application States

Application State	Motor State	Green LED State
Stopped	Stopped	Blinking at a frequency of 2Hz
Running	Spinning	On
Fault	Stopped	Blinking at a frequency of 8Hz

2. **PC Master Software (Remote) Operating Mode**
   The drive is controlled remotely from a PC through the SCI communication channel of the hybrid controller via an RS-232 physical interface. The drive is enabled by the RUN / STOP switch, which can be used to safely stop the application at any time. PC master software enables the user to set the motor's Required Speed.

The following PC master software control actions are supported:

- Set the motor control system's PC master software mode
- Set the motor control system's manual mode
- Start the motor
- Stop the motor
- Set the motor's Required Speed

PC master software displays the following information:

- The motor's Required Speed
- The motor's Actual Speed
- Application status
  - Init
  - Stop
  - Run
  - Fault
- DCBus voltage level
- Identified line voltage
- Fault Status
  - No_Fault
  - Overvoltage
  - Overcurrent
  - Undervoltage
  - Overheating

Start the PC master software window's application, *3ph_pmsm_vector_control.pmp*. **Figure 1-3** illustrates the PC master software control window after this project has been launched.

Note: If the PC master software project (*.pmp* file) is unable to control the application, it is possible that the wrong load map (*.elf* file) has been selected. PC master software uses the load map to determine addresses for global variables being monitored. Once the PC master software project has been launched, this option may be selected in the PC master software window under *Project* / *Select Other Map File Reload*.

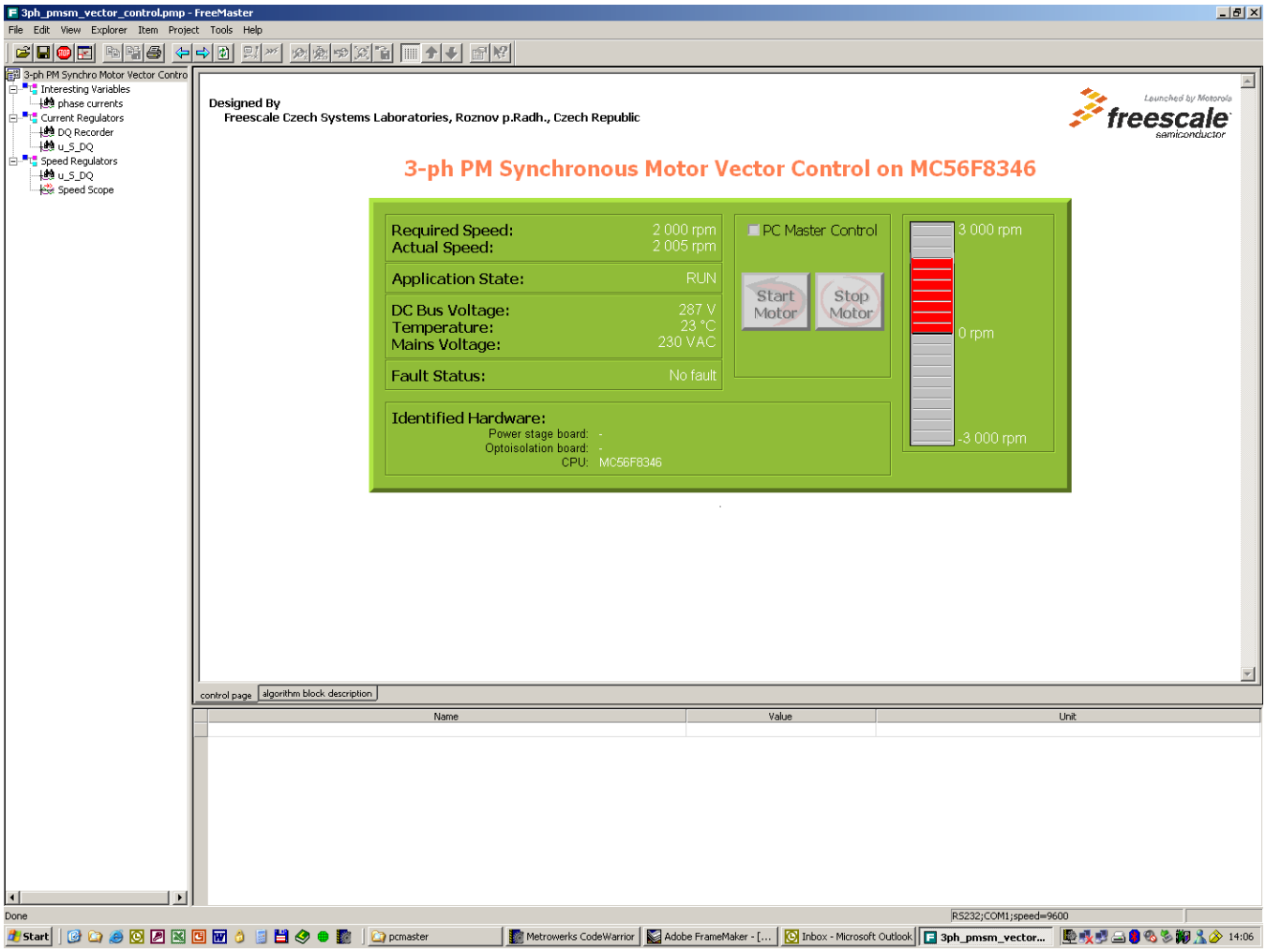

Figure 1-3 PC master Software Control Window

2. Hardware Set-up

Figure 2-1 illustrates the hardware set-up for the 3-phase Permanent Magnet Synchronous Motor (PMSM) Vector Control Application.

WARNING:

Danger, high voltage—risk of electric shock!

The application PCB modules and serial interface (connector, cable) are not electrically isolated from the mains voltage—they are live.

Use the In-line Optoisolation Box (ECOPTINL) between the PC and the MC56F83xxEVM as protection from dangerous voltage on the PC-user side, and to prevent damage to the PC and other hardware.

Do not touch any part of the EVM or the serial cable between the EVM and the In-line Optoisolation Box unless you are using an insulation transformer. The application is designed to be fully controllable only from PC master software.

To avoid inadvertently touching live parts, use plastic covers.

In the rest of this application, the description supposes use of the insulation transformer.

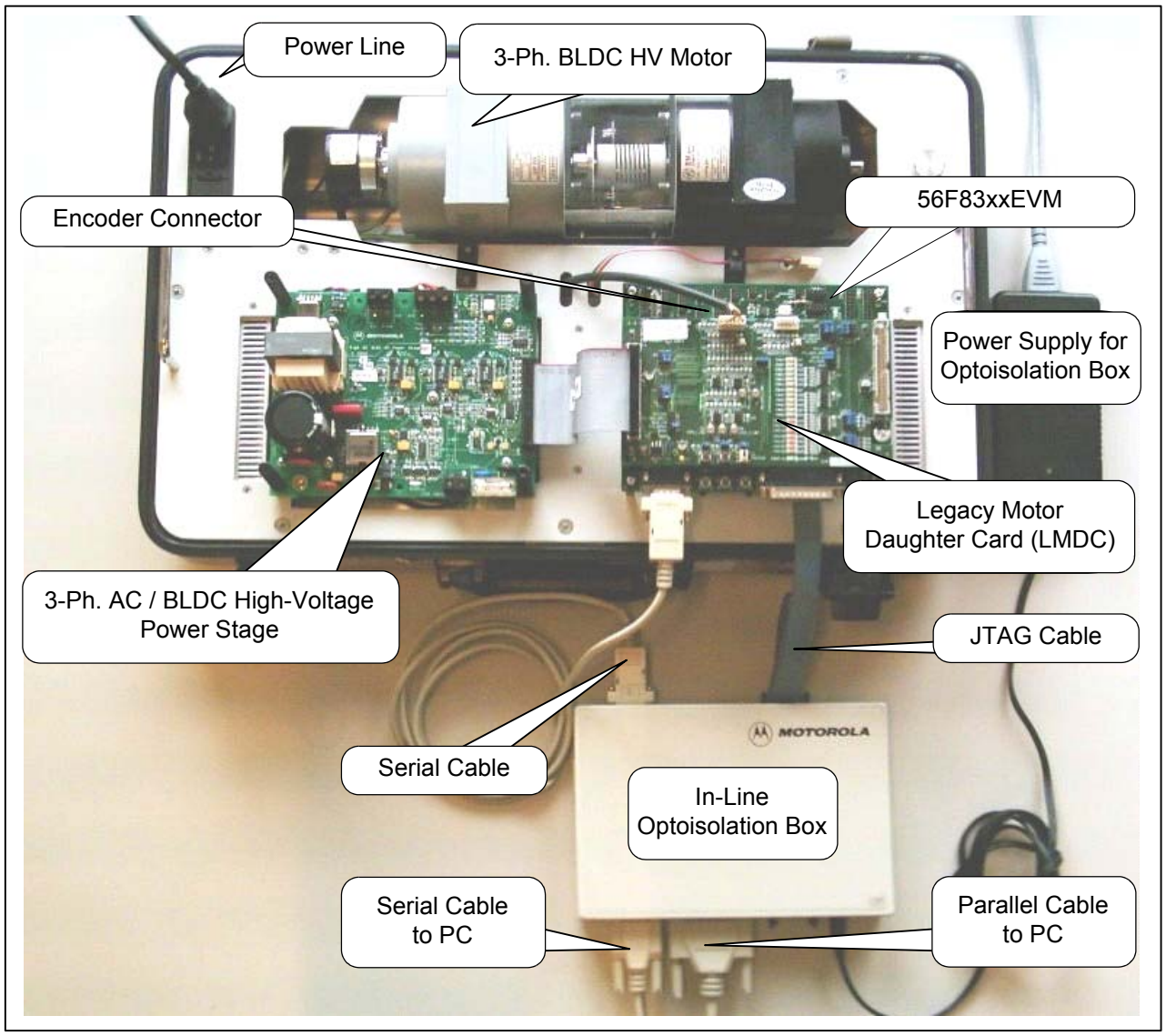

Figure 2-1 Application Set-up

The correct order of phases for the AC induction motor shown in **Figure 2-1** is:

- Phase A = red wire
- Phase B = white wire
- Phase C = black wire

When facing a motor shaft, the phase order is: Phase A, Phase B, Phase C; the motor shaft should rotate clockwise (i.e., positive direction, positive speed).

For detailed information, see the **56F83xxEVM Hardware User Manual** for the device being implemented. The serial cable is needed only for the PC master software debugging tool.

2.1 EVM Jumper Settings

For jumper settings, see the **56F8346 Evaluation Module Hardware User's Manual, 56F8357 Evaluation Module Hardware User's Manual** or **56F8367 Evaluation Module Hardware User's Manual**.

Note: When running the EVM target system in a stand-alone mode from Flash, in the **56F8346EVM,** the **JG9** jumper must be set in the 1-2 configuration to disable the command converter parallel port interface. In the **56F8357EVM** or the **56F8367EVM**, the **JG3** jumper must be set in the 1-2 configuration to disable the command converter parallel port interface.

For a detailed description for jumper settings, see the appropriate **56F83xx Evaluation Module Hardware User's Manual** for the device being implemented.

2.1.1 Legacy Motor Daughter Card (LMDC) Jumper Settings

To execute the 3-phase PMSM Vector Control Application, the 56F8300 LMDC requires the strap settings shown in **Figure 2-2** and **Table 2-1**.

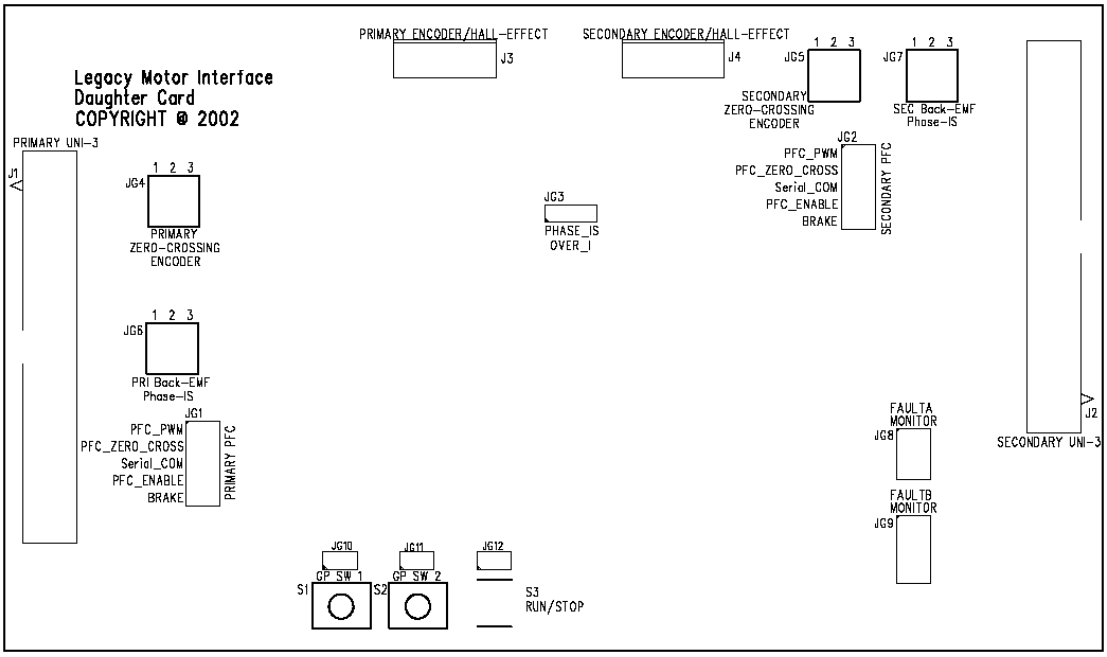

Figure 2-2 56F8300EVM LMDC Jumper Reference

Table 2-1 56F8300EVM LMDC Jumper Settings

Jumper Group	Comment	Connections
JG1	Primary PFC	1-2 & 3-4 & 5-6 & 7-8 & 9-10
JG2	Secondary PFC	NC
JG3	Phase_IS / Over_I	2-3
JG4	Primary Zero-Crossing / Encoder	2-3 & 5-6 & 8-9
JG5	Secondary Zero-Crossing / Encoder	2-3 & 5-6 & 8-9
JG6	Primary Back-EMF / Phase-IS	1-2 & 4-5 & 7-8
JG7	Secondary Back-EMF / Phase-IS	1-2 & 4-5 & 7-8
JG8	Fault A Monitor	1-2 & 3-4 & 5-6
JG9	Fault B Monitor	1-2 & 3-4 & 5-6
JG10	Switch 1 (Up)	1-2
JG11	Switch 2 (Down)	1-2
JG12	Switch 3 (Run / Stop)	1-2

3. Build

To build this application, open the *3ph_pmsm_vc_56F83xx_onPE.mcp* project file and execute the *Make* command, as shown in **Figure 3-1**. This will build and link the 3-phase PMSM Vector Control Application and all needed *Metrowerks* and *Processor Expert* libraries.

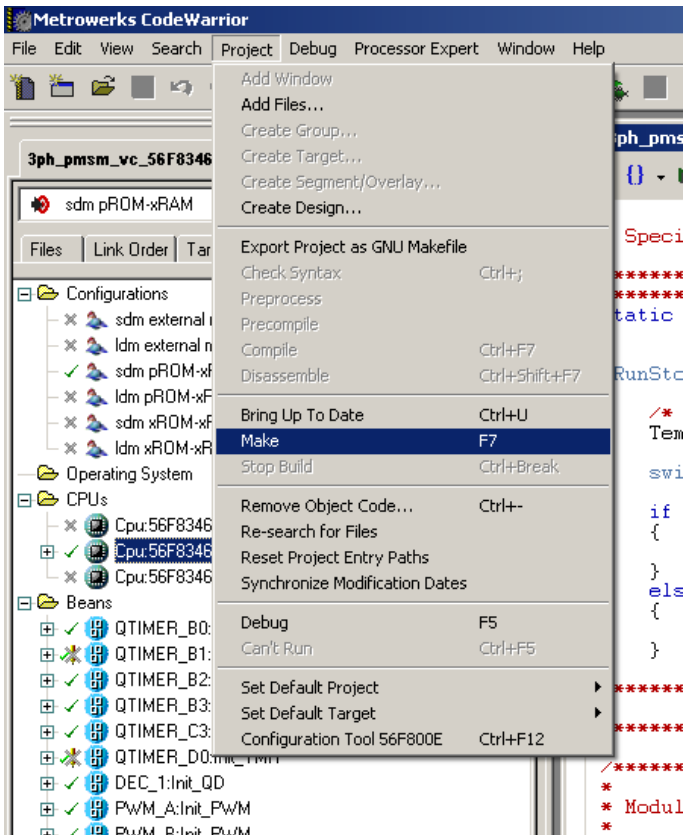

Figure 3-1 Execute *Make* Command

4. Execute

To execute the 3-phase PMSM Vector Control application, select *Project / Debug* in the CodeWarrior IDE, followed by the *Run* command.

If the *Flash* target is selected, CodeWarrior will automatically program the internal Flash of the hybrid controller with the executable generated during *Build*. If the *External RAM* target is selected, the executable will be loaded to off-chip RAM.

To execute the 3-phase PMSM Vector Control Application's internal Flash version, choose the *Program / Debug* command in the CodeWarrior IDE and when loading is finished, in the **56F8346EVM**, set jumper **JG9** to disable the JTAG port and **JG3** to enable boot from **internal Flash**, then push the RESET button. In the **56F8357EVM** or the **56F8367EVM**, set jumper **JG3** to disable the JTAG port and **JG4** to enable boot from **internal Flash**, then push the RESET button.

For more help with these commands, refer to the CodeWarrior tutorial documentation in the following file, located in the CodeWarrior installation directory:

<...>\CodeWarrior Manuals \ PDF \ Targeting_56800E.pdf

For jumper settings, see the appropriate **56F83xx Evaluation Module Hardware User's Manual** for the device being implemented.

Once the application is running, move the RUN / STOP switch to the RUN position and set the required speed with the UP / DOWN push buttons. Pressing the UP / DOWN buttons should incrementally increase the motor speed until it reaches maximum speed. If successful, the 3-phase PMSM will be spinning.

Note: If the RUN / STOP switch is set to the RUN position when the application starts, toggle the RUN / STOP switch between the STOP and RUN positions to enable motor spinning. This is a protection feature that prevents the motor from starting when the application is executed from CodeWarrior. You should also see a lighted green LED, which indicates that the application is running. If the application is stopped, the green LED will blink at a 2Hz frequency. If an undervoltage, overvoltage, overcurrent, or overheating fault occurs, the green LED will blink at a frequency of 8Hz.

How to Reach Us:

Home Page:
www.freescale.com

E-mail:
support@freescale.com

USA/Europe or Locations Not Listed:
Freescale Semiconductor
Technical Information Center, CH370
1300 N. Alma School Road
Chandler, Arizona 85224
+1-800-521-6274 or +1-480-768-2130
support@freescale.com

Europe, Middle East, and Africa:
Freescale Halbleiter Deutschland GmbH
Technical Information Center
Schatzbogen 7
81829 Muenchen, Germany
+44 1296 380 456 (English)
+46 8 52200080 (English)
+49 89 92103 559 (German)
+33 1 69 35 48 48 (French)
support@freescale.com

Japan:
Freescale Semiconductor Japan Ltd.
Headquarters
ARCO Tower 15F
1-8-1, Shimo-Meguro, Meguro-ku,
Tokyo 153-0064, Japan
0120 191014 or +81 3 5437 9125
support.japan@freescale.com

Asia/Pacific:
Freescale Semiconductor Hong Kong Ltd.
Technical Information Center
2 Dai King Street
Tai Po Industrial Estate
Tai Po, N.T., Hong Kong
+800 2666 8080
support.asia@freescale.com

For Literature Requests Only:
Freescale Semiconductor Literature Distribution Center
P.O. Box 5405
Denver, Colorado 80217
1-800-441-2447 or 303-675-2140
Fax: 303-675-2150
LDCForFreescaleSemiconductor@hibbertgroup.com

Information in this document is provided solely to enable system and software implementers to use Freescale Semiconductor products. There are no express or implied copyright licenses granted hereunder to design or fabricate any integrated circuits or integrated circuits based on the information in this document.

Freescale Semiconductor reserves the right to make changes without further notice to any products herein. Freescale Semiconductor makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does Freescale Semiconductor assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation consequential or incidental damages. “Typical” parameters that may be provided in Freescale Semiconductor data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including “Typicals”, must be validated for each customer application by customer’s technical experts. Freescale Semiconductor does not convey any license under its patent rights nor the rights of others. Freescale Semiconductor products are not designed, intended, or authorized for use as components in systems intended for surgical implant into the body, or other applications intended to support or sustain life, or for any other application in which the failure of the Freescale Semiconductor product could create a situation where personal injury or death may occur. Should Buyer purchase or use Freescale Semiconductor products for any such unintended or unauthorized application, Buyer shall indemnify and hold Freescale Semiconductor and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that Freescale Semiconductor was negligent regarding the design or manufacture of the part.

Freescale™ and the Freescale logo are trademarks of Freescale Semiconductor, Inc.
All other product or service names are the property of their respective owners.
This product incorporates SuperFlash® technology licensed from SST.

© Freescale Semiconductor, Inc. 2004. All rights reserved.

8300PMSMTD
Rev. 0
1/2005